ESTIMATING THE EFFECTS OF AGRICULTURAL CONSERVATION PRACTICES ON PHOSPHORUS LOADS IN THE MISSISSIPPI-ATCHAFALAYA RIVER BASIN

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ABSTRACT. *Agriculture in the Mississippi-Atchafalaya River basin (MARB) is important in terms of both the national economy and the nutrients discharged to the basin and the Gulf of Mexico. Conservation practices are installed on cropland to reduce the nutrient losses. A recent study by the Conservation Effects Assessment Project (CEAP) determined the effects of agricultural conservation practices on water quality in the MARB. A modeling framework consisting of a farm-scale model (Agricultural Policy Environmental Extender, APEX), a watershed-scale model (Soil and Water Assessment Tool, SWAT), and databases was used. APEX was used to simulate the conservation practices on cropland and Conservation Reserve Program (CRP) land and assess the edge-of-field water quality benefits. The predicted flow and loads from APEX were input to SWAT, and SWAT was used to simulate the watershed processes and estimate the local and instream water quality benefits. The model was used for scenario assessment after calibration and validation for streamflow and loads. Recent studies indicate that phosphorus influences the formation of the hypoxic zone in the Gulf of Mexico. The major objectives of this article are to: (1) estimate and discuss the effects of currently existing and additional conservation practices on total phosphorus (TP) loads in the MARB, and (2) assess how TP loads discharged by the conservation scenarios can achieve the recommended annual P target for hypoxia reduction. Results indicated that current conservation practices on cropland have reduced TP losses to local waters by 13% to 52% in six basins within the MARB and reduced the TP load discharged to the Gulf of Mexico by 22%. Additional P load reduction is likely required to reach the annual P target for hypoxia reduction.*

Keywords. *Agriculture, APEX, CEAP, Conservation practices, Mississippi, Phosphorus, SWAT.*

Agricultural nonpoint-source (NPS) pollution is reported to be the major source of impairment in many water bodies throughout the U.S. (USEPA, 2005). The U.S. Environmental Protection Agency (USEPA) administers several Clean Water Act programs, including Total Maximum Daily Load (TMDL), and 319 projects to control NPS pollution (USEPA, 2005). The USDA has continuously implemented many conservation programs over decades to protect and improve natural resources and agricultural production. The practices promoted include: (1) land-shaping structural practices and sediment control structures, (2) conservation tillage with crop rotations and cover, (3) establishment of Conservation Reserve Program (CRP) for erodible cropland, and (4) nutrient management practices. Public awareness has increased to demand for real evidence of environmental benefits for the dollars spent (Richardson et al., 2008). Hence, the USDA initiated the Conservation Effects Assessment Project (CEAP) to estimate the benefits and impacts of current cropland conservation practices at the regional and national levels. An analytical framework consisting of statistical sampling and farmer surveys to derive land management inputs, as well as modeling approaches for simulating conservation practices, was developed in CEAP for national and regional cropland assessment. The CEAP framework was used to quantify the environmental benefits of conservation practices on cropland in the U.S. (Mausbach and Dedrick, 2004). Estimating the environmental benefits of conservation practices will provide information to policy-makers and conservation program managers to help them evaluate the benefits of existing programs and design future programs more effectively.

Several CEAP benchmark watersheds are located within the Mississippi-Atchafalaya River basin (MARB), including Goodwater Creek in Missouri, Upper Walnut Creek in Ohio, Upper Washita River in Oklahoma, North Walnut Creek and South Fork in Iowa, and Goodwin Creek Exper-

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imental Watershed in Mississippi. The CEAP watershed studies allowed detailed calibration at a smaller scale than was possible using USGS gauges. In addition, the CEAP watershed data provided the opportunity to test individual processes and specific conservation practices at watershed scale (Richardson et al., 2008). Processes and conservation practice algorithms that were improved during the CEAP project include: subsurface drainage, animal waste management, fertilizer rate and timing, flood control structures, channel erosion, and riparian processes. The CEAP watershed study information is compiled in STEWARDS (www.ars.usda.gov/Research/docs.htm?docid=18622). The MANAGE database provides similar information from watersheds across the U.S. (Harmel et al., 2006). One of the purposes of the CEAP watershed study was to provide information for validation and verification in the CEAP National Cropland Assessment. The development and validation of the new and improved routines incorporated in the models gave increased confidence in predictions of the CEAP National Cropland Assessment.

Agriculture in the MARB is important for the U.S., as it produces the majority of the corn and soybeans in the country. At the same time, the fertilizers and manure applied on agricultural land in the MARB are reported to be a major source of nutrient loadings (nitrogen and phosphorus) to the Mississippi River and the Gulf of Mexico (Goolsby and Battaglin, 2001; Alexander et al., 2008; USEPA, 2011b). Other sources, such as point-source discharges from municipal and industrial facilities, manure applied on grassland, and urbanization, also contribute to nutrient pollution. Excess nutrients discharged from the MARB result in a low dissolved oxygen area, called the hypoxic zone, in the Gulf of Mexico (Rabalais et al., 2002; USEPA, 2007). Hypoxia affects aquatic organisms and is a potential threat to the nation's productive fisheries and related economy. Although nitrogen (N) from agriculture is the primary nutrient contributing to hypoxia (Rabalais et al., 2002; USEPA, 2007; Alexander et al., 2008), recent studies have indicated that phosphorus (P) is also important. P discharged from the MARB during spring and summer influences the formation of hypoxia (Sylvan et al., 2006; Scavia and Donnelly, 2007; USEPA, 2011b). Sylvan et al. (2006) recommended including P in strategies to decrease the occurrence of hypoxia. Thus, reducing nutrient pollution from agricultural lands through conservation is important to manage the water quality conditions within the MARB and in the Gulf of Mexico. Given these facts, not much attempt has been made to relate conservation in agriculture with P in the MARB and annual target P loads for reducing hypoxia in the Gulf of Mexico. Hence, this article explores how P loads delivered to local waters in the MARB, to the Mississippi River, and to the Gulf of Mexico can be reduced through current agricultural conservation practices and additional practices from the CEAP modeling study. Conservation agencies and environmental agencies can use this information to make decisions on where to allocate resources for future agricultural conservation planning, source load allocations for TMDL, and further efforts required attain the hypoxia target.

Several researchers have studied nutrients in the MARB in terms of nutrient inputs, sources, and delivery, as well as the relationship of nutrients to hypoxia in the Gulf of Mexico (Alexander et al., 2000; Scavia and Donnelly, 2007; Alexander et al., 2008; David et al., 2010; USEPA, 2011b). This study differs from those previous studies in perspective and focus. This study specifically examines the effects of current and additional agricultural conservation practices on water quality (mainly P) in the MARB using an integrated modeling approach. This study also assesses how P loads discharged from the MARB to the Gulf of Mexico under current and additional agricultural conservation efforts can be reduced to reach the recommended annual target P loads for hypoxia reduction. The specific objectives of this study are to:

1. Spatially characterize the total phosphorus (TP) losses (load per hectare) to local waters from cultivated cropland and CRP land in each 8-digit watershed in the MARB due to currently established agricultural conservation practices and increased additional conservation practices.
2. Estimate the TP loads delivered to local and instream or riverine waters in the MARB under currently established agricultural conservation practices and increased additional conservation treatment practices, as well as the TP reductions due to conservation.
3. Compare the annual TP loads discharged from the MARB to the Gulf of Mexico under various agricultural conservation conditions with the target P loads for hypoxia reduction to determine how much further P reduction is required to meet the target.

In this study, currently established conservation practices (also referred as the baseline conservation condition scenario) include all practices on cropland during the 2003-2006 period. Additional conservation practices (also referred as enhanced nutrient management practice scenarios ENMC and ENMA) include additional erosion and nutrient management practices attempted on cropland fields to reduce sediment and nutrient losses.

Materials and Methods

CEAP Cropland Assessment: Modeling Framework

Conservation practices are implemented under varying weather, soils, and land management conditions across the region; hence, their effects vary depending on local conditions. A process-based, regional-scale hydrologic modeling system with a geographic information system (GIS) captures the spatial and temporal variations and interactions of weather, hydrology, land use management, crops, soils and pollutant sources and quantifies the effects of conservation practices on water quality in a river basin. In addition, monitoring data are required for calibrating and validating the model, as well as for assessing the effects of conservation practices. The validated model can be used to evaluate the existing conservation programs, verify alternative management options, and target future efforts on critical areas to gain major benefits.

The CEAP modeling framework is a national-scale modeling framework developed to address agricultural and environmental management programs and water quality issues in the U.S. (Arnold et al., 2010; Di Luzio et al., 2008; Santhi et al., 2014; White et al., 2014) since the mid-2000s with financial support from the USDA. The CEAP modeling framework evolved from its ancestor, called HUMUS (Hydrologic Unit Modeling for the U.S.), that used SWAT in the 1990s to address agricultural and water quality issues in the U.S. (Srinivasan et al., 1998; Arnold et al., 1998). The CEAP modeling framework consists of two models, updated databases, and is much more detailed than HUMUS. Within the CEAP modeling framework, each of 18 major river basins (2-digit) in the U.S. is treated as a basin, and each 8-digit watershed is treated as a subbasin. A field-scale model, Agricultural Policy Environmental Extender (APEX) (Williams and Izaurralde, 2006), is used to simulate the cropland portion of the basin, and a watershed-scale model, Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998; Neitsch et al., 2002), is used to simulate the non-cropland portion of the watershed. Both models are used to assess the effects of conservation practices at different scales in a basin in CEAP. The CEAP modeling framework consists of the following:

- APEX is used to simulate cultivated cropland and CRP land, structural practices, and cultural management practices implemented on those lands in each 8-digit watershed in the basin (table 1) and assess the effectiveness of the practices on water quality, such as runoff, soil erosion, and nutrient and pesticide losses at the edge of the field. The edge-of-field runoff, sediment, soluble and organic forms of N and P, and pesticide losses from each APEX cropland subarea (simulation unit) are applied with delivery ratios, area weighted and summed for each 8-digit watershed, to a get single input file and integrated with SWAT for each 8-digit watershed.
- SWAT is used to simulate the upland processes of hydrology, farming operations, crop growth, deposition of atmospheric N, and fate and transport of water, sediment, nutrients, and pesticides from remaining non-cultivated land, such as pasture, range, urban, forest, and other land uses, to each 8-digit watershed outlet in the basin. SWAT then simulates the routing and in-stream processes of water, sediment, nutrients, and pesticides from non-cultivated land, point-source discharges, and cultivated cropland and CRP inputs from APEX through the channels, reservoirs, and lakes in each 8-digit watershed to the basin outlet. The output from SWAT is used to assess the effects of conservation practices on local and instream water quality.
- A geo-database consisting of land use, soils, land management, topography, weather, point sources, and atmospheric depositions of N is used to develop inputs for both models at the 8-digit watershed scale for river basins in the U.S.

The reasons for using APEX with SWAT for CEAP cropland assessment are that this method (1) allows simulation of cultivated lands with conservation practices to proceed either independently of or simultaneously with watershed simulation and watershed benefits of the practices,

Table 1. Basin details, including extent of conservation practices in use, critically undertreated areas, and all undertreated areas in the Mississippi-Atchafalaya River basin (sources: USDA-NRCS, 2011, 2012a, 2012b, 2013).

Basin Details	Ohio-Tennessee	Upper Mississippi	Lower Mississippi	Missouri	Arkansas White-Red
Average annual rainfall (mm)	1067	864	1340	584	803
Average annual runoff (mm)	450 Ohio 650 Tennessee	203	480	89	150
Basin area (km^2)	527,680	491,748	271,546	1,321,593	642,157
Cropland and CRP land (%)	21	54	30	29	22
Critically undertreated cropland area (km^2) (expressed as percentage of cropped area)	36,342 (34%)	24,330 (10%)	25,467 (9%)	4,561 (1%)	5,277 (4%)
All undertreated cropland area (km^2) (expressed as percentage of cropped area)	70,894 (65%)	142,444 (56%)	65,856 (24%)	61,943 (16%)	42,076 (29%)
Structural practices	Cultivated Cropland (%)				
In-field overland flow control practices, such as contour farming, strip cropping, contour buffer strips, terraces, grass terraces, and tile drains	15	21	13	32	42
In-field concentrated flow control practices, such as grade stabilization structures, grassed waterways, and diversions	26	32	10	21	23
Edge-of-field buffering and filtering practices, such as filter strips, riparian forest buffers, riparian herbaceous cover, and field borders	10	9	3	3	2
Wind erosion control practices	2	3	1	10	7
Cultural practices: Residue and tillage management practices	Cultivated Cropland (%)				
No-till or mulch till used in crop rotation	93	91	81	93	58
Reduced tillage on some crops in rotation, but average annual tillage intensity greater than criteria for mulch till	3	4	7	4	8
Continuous conventional tillage in every year of crop rotation	4	5	10	3	34
Cultural practices: Nutrient management practices for P	Cultivated Cropland (%)				
Crops in rotations meeting the appropriate rate, timing, and method of P application[a]	21	28	14	41	29
P not applied to any crop in rotation	<1	<1	4	7	21
Cover crops	2	<1	<1	<1	<1
Long-term cover establishment and/or CRP as a percent of cropland	4	5	5	12	17

[a] Appropriate rate = 1.1 times removal at harvest, appropriate timing = applications within three weeks before planting or after planting, and appropriate method = incorporation or banding, foliar, or spot treatment.

(2) allows detailed simulation of complex agronomic practices and conservation practices at field scale on cultivated lands using APEX, and (3) allows SWAT to simulate non-cropland and transport of flow and other constituents from all sources through detailed in-stream channel and reservoir processes in the basin and assess the watershed-level benefits in the river basin. The CEAP modeling framework has the capability to simulate landscape and instream processes occurring in a large-scale basin, and the model accuracy can be improved through calibration and proper representation of the physical processes. The CEAP modeling framework can also simulate and evaluate current and future conservation practices and agricultural management conditions at various time and spatial scales. These strengths can complement other regional models, such as SPARROW (Spatially Referenced Regressions on Watershed attributes) (Alexander et al., 2008; Schwarz et al., 2011). A brief description of the simulation of land management practices in APEX and SWAT, the CEAP survey, and conservation practices is provided in the Appendix. Details on the CEAP modeling framework, databases, and model inputs can be found in Santhi et al. (2014), Arnold et al. (2010), and Di Luzio et al. (2008). Details on the calibration and validation of SWAT and APEX, including parameterization, can be found in Santhi et al. (2014), White et al. (2014), and Wang et al. (2012). Hence, this article briefly describes the above listed items only as needed and focuses more on the stated objectives.

Models and Sources Integration

Sediment yields were estimated using MUSLE for each non-cropland hydrologic response unit (HRU) in SWAT (Neitsch et al., 2002) and each cropland field in APEX (Williams and Izaurralde, 2006). After estimating the sediment load for each HRU or APEX simulation field, a delivery ratio was applied to determine the amount of sediment that reaches the 8-digit watershed outlet from each HRU or cropland subarea. Sediment delivery ratios were estimated as a function of the time of concentration of HRU in SWAT or cropland subarea in APEX to the time of concentration of the 8-digit watershed. The delivery ratios used in both models for CEAP were slightly different from those reported in the SWAT documentation. In CEAP, they account for the deposition of sediment and nutrients in channels and floodplains during transport from the edge of the cropland field and from non-cropland HRUs to the 8-digit watershed outlet. Delivery ratios vary over time in a year. They also vary for each HRU or cropland subarea in the 8-digit watershed. Delivery losses of soluble nutrients were assumed to be 3% to 10%. Details on the delivery ratio procedure can be found in Wang et al. (2011) and Santhi et al. (2011). Wang et al. (2011) described the procedure for integrating APEX with SWAT, the upland sediment delivery ratio, the CEAP survey sampling approach, and simulation of conservation practices with APEX using the Upper Mississippi River basin as an example.

Flow, sediment, and nutrient and pesticide losses from each APEX cropland subarea (simulation unit) were area weighted and added for each 8-digit watershed to a get single input file. This input file represented the flows and loads from the cropland area in each 8-digit watershed and was integrated with SWAT. SWAT simulated the flows and loads delivered to each 8-digit watershed from non-cropland HRUs. Effluent discharged from municipal, industrial, and small point-source sanitary facilities (Gianessi and Peskin, 1984) were updated and aggregated for each 8-digit watershed, and average annual loads were input into SWAT with delivery ratios. Delivery ratios were used in this case to account for nutrients losses in transit from discharging locations to the 8-digit watershed outlet. Flows and source loads predicted from cultivated cropland and CRP, non-cultivated land, and point sources were discharged into each 8-digit watershed (fig. 1) and routed through each downstream watershed to the basin outlet with accounting of the instream processes, such as sediment degradation, streambed deposition, streambank erosion, nutrient transformation, and trapping of pollutants in reservoirs and lakes (Neitsch et al., 2002). The input data to both models were modified to accommodate the integration.

Modeling of Phosphorus by APEX and SWAT

Both APEX and SWAT simulate the P cycle, which includes soil, water, and plants. P may be added to the soil by fertilizer, manure, or residue application. P is removed from the soil by plant uptake and erosion (Williams and Izaurralde, 2006; Arnold et al., 1998; Neitsch et al., 2002). SWAT simulates nutrient transformations in streams and rivers using the nutrient routines adapted from QUAL2E (Brown and Barnwell, 1987). SWAT tracks the P dissolved in the stream and the P adsorbed to sediment. While soluble P is transported with the water, particulate P sorbed to sediment may deposit in the channel. P cycling between organic and soluble forms associated with algae growth and interaction with the benthic environments is also simulated. SWAT also simulates P routing through impoundments such as reservoirs, lakes, and ponds (Arnold et al., 1998; Neitsch et al., 2002).

Mississippi-Atchafalaya River Basin: Background and Pollution Status

The Mississippi River along with the Atchafalaya River (fig. 2) drains nearly 3.2 million km^2 and discharge into the Gulf of Mexico. The MARB consists of six river basins (fig. 2) draining into the Mississippi River. Each basin has different characteristics (table 1 and fig. 2). Corn-soybean rotations as well as corn, soybean, wheat, hay, and close crops are grown extensively in the MARB. Precipitation and annual runoff are generally lower in the western part of the MARB and higher in the eastern part. Tile drainage is mostly distributed in the Corn Belt states of Iowa, Illinois, Indiana, Ohio, and some parts of Minnesota. Tile drainage was simulated on cropland using the CEAP survey information and APEX. For modeling tile flow, APEX uses the depth to subsurface tile drains, the time (in days) required to drain the soil without plant stress, the saturated hydraulic conductivity of the soil layer with tile, and a coefficient to adjust the saturated hydraulic conductivity of the soil layer with tile (Jimmy Williams, APEX model developer, personal communication, March 2014). The saturated hydrau-

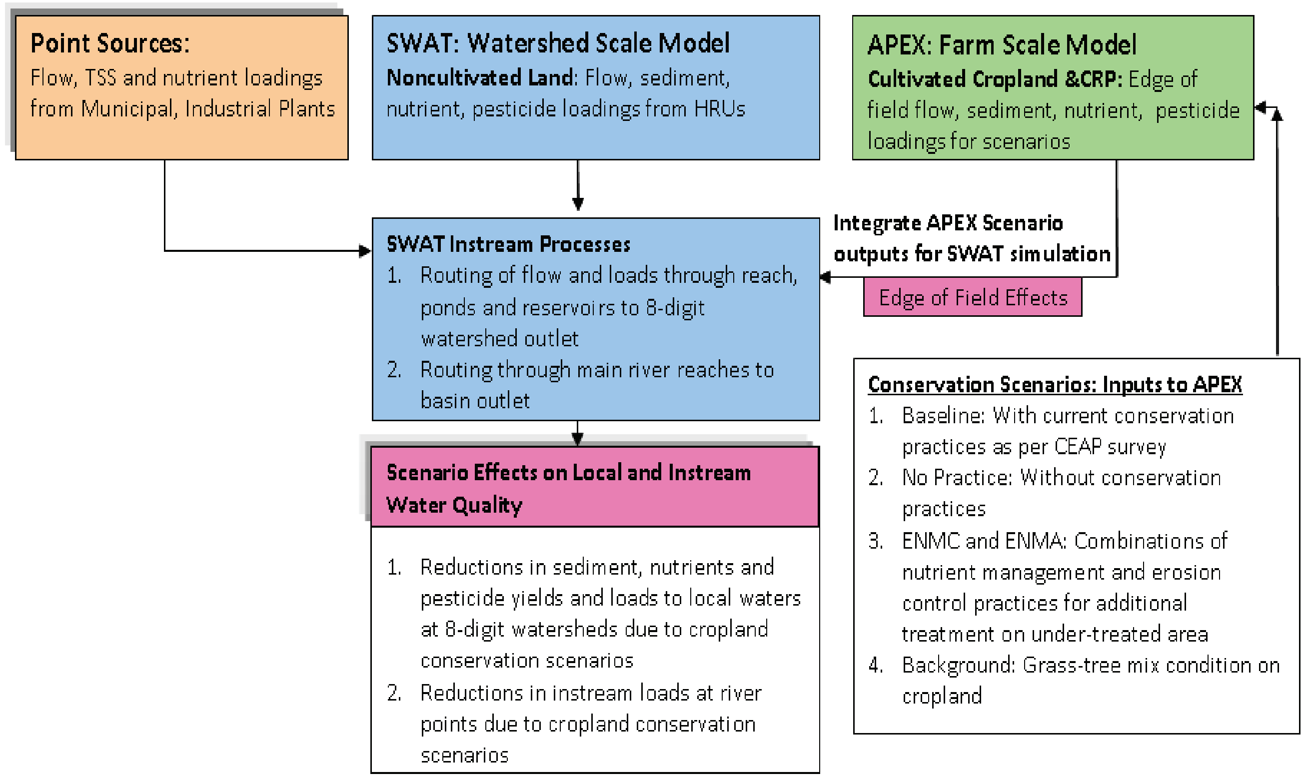


Figure 1. Integration of models and sources for conservation scenarios.

lic conductivity coefficient for tile drainage in APEX was used to control the upper limit of tile flow. This parameter ranged from 0.3 to 8.0 (Wang et al., 2011). Tile drains are one of the sources of dissolved P to rivers and streams, as indicated by Gentry et al. (2007). A portion of streamflow (approx. 30%) along with sediment, nutrients, and pesticides from the Mississippi River are diverted below Vicksburg, Mississippi, into the Old River Outflow Channel and the Atchafalaya River (fig. 2).

As a major production area for grain, agriculture is the major contributor of nutrients from the MARB to the Mississippi River and the Gulf of Mexico (Goolsby and Battaglin, 2001). Wastewater discharges from cities and suburbs, conversion of land to agricultural and urban use, increased runoff from urban areas, and discharges from feedlots and other sites of intensive agricultural activity also contribute nutrients to the rivers. Excessive nutrients discharged annually from the MARB, especially during spring and summer, influence the production of algae biomass and development of the hypoxic zone (Rabalais et al., 2002; Sylvan et al., 2006; Scavia and Donnelly, 2007; USEPA, 2011b). The EPA's Science Advisory Board recommended a 45% load reduction target for annual P discharged to the Gulf of Mexico to reduce the size of the hypoxic zone to 5,000 km^2 in 2015 (USEPA, 2007, 2011b). The 2005 Wadeable Streams Assessment by the USEPA (2011a) indicated that 32% of streams in the basin have high levels of P. Conservation practices in the entire Mississippi River basin have become important for controlling nutrients discharged within the MARB as well as to the Gulf of Mexico. Conservation practices have been implemented for several decades in the MARB (table 1) to protect and improve natural resources and agricultural production (USDA-NRCS, 2011, 2012a, 2012b, 2013).

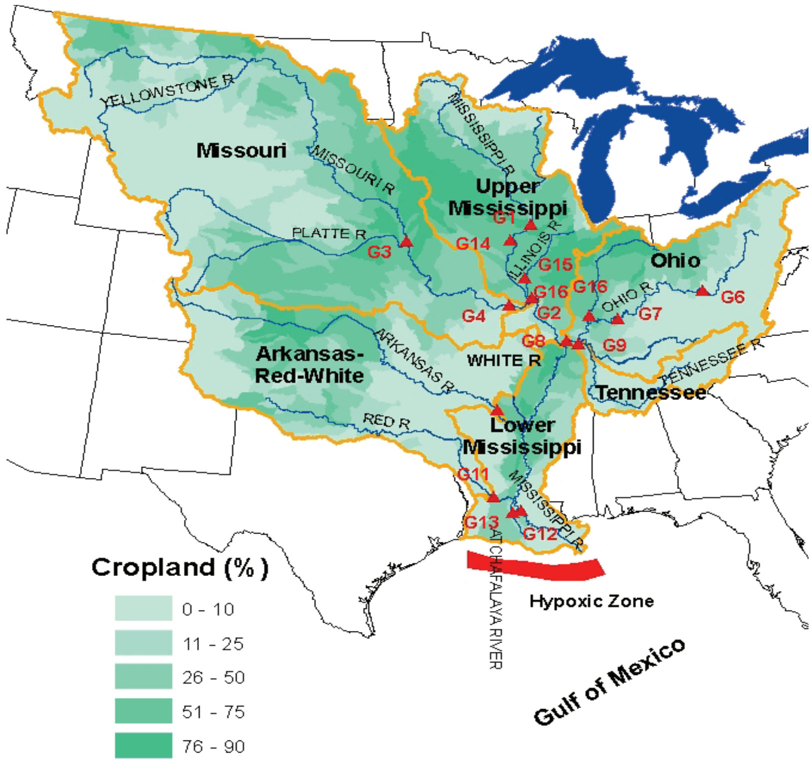
Conservation Practice Scenarios

The MARB model was calibrated for water yield in all (848) of the 8-digit watersheds within the basin and for streamflow, sediment, and N and P loads at multiple gauging sites between 1961 and 2006, as described briefed in the Appendix. The calibrated model was used to simulate and assess the long-term effects of five conservation practice scenarios on off-site water quality in the MARB. Long-term effects capture the changes in hydrology and fluxes due to weather variability.

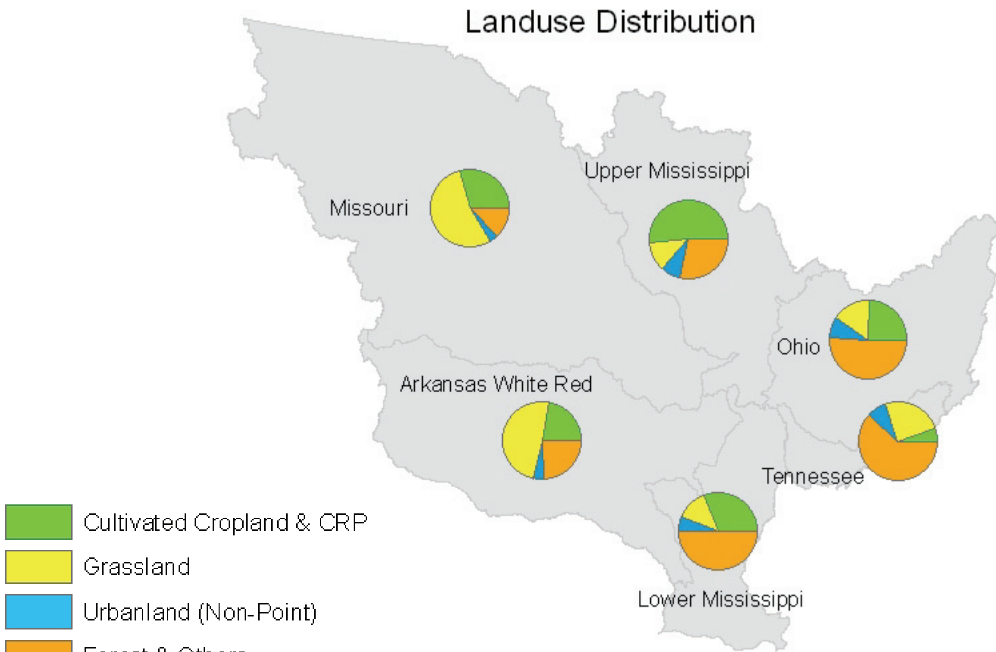
As described below, for each scenario, the management conditions for cultivated cropland were modified in APEX, while the SWAT management conditions, inputs and point sources, remained unchanged. Aggregated edge-of-field flows and loads from APEX for each scenario were integrated with SWAT for each 8-digit watershed. While APEX assessed the effectiveness of the practices on water quality at the edge of the field for each scenario, SWAT assessed the effectiveness of the practices on local and instream or riverine water quality for each scenario (fig. 1).

Baseline (Current) Conservation Condition Scenario

APEX simulations were made for cultivated cropland and CRP land with the cropping patterns, farming activities, and conservation practices in use during 2003 to 2006 for determining the baseline conservation conditions. The baseline conservation conditions provide a benchmark for estimating the effects of existing conservation practices.



(a)



(b)

Figure 2. Mississippi-Atchafalaya River basin (see tables A-1 and A-2 in the Appendix). "Grassland" includes uncultivated pasture, range, and hay. "Forests and others" includes evergreen, mixed, and deciduous forest as well as forested and non-forested wetlands, barren land, water, and minor orchards and vegetable cultivation.

No-Practice Scenario

For the no-practice scenario, APEX simulations were made for cultivated cropland using farmer survey records assuming no conservation practices were used on cropland and CRP but holding all other model inputs and parameters the same as in the baseline conservation condition scenario.

ENMC and ENMA Scenarios

Two conservation treatment scenarios were simulated to evaluate the potential gains from further conservation treatments compared to the baseline conservation conditions. The first, referred to as the ENMC (enhanced nutrient management of critical undertreated acres) scenario, represents the treatment of acres that were determined to have a high need for additional treatment. The second, referred to as the ENMA (enhanced nutrient management of all undertreated acres) scenario, represents the treatment of acres that were determined to have either a high or moderate need for additional treatment. A critically undertreated area is a subset of all undertreated areas. Thus, the ENMC scenario simulates treatment of only that portion of the acres treated in the ENMA scenario that have the most critical need for additional treatment (table 1). The two simulated treatment scenarios differed in the number of acres treated.

In this study, undertreated cropland is defined as cropland where the level of conservation practice use is inadequate relative to the level of inherent vulnerability due to soils and climate. The level of conservation treatment need (high, moderate, or low) was determined using a matrix approach that compared the extent to which the cropland acres in the baseline conservation condition are inadequately treated with respect to the potential vulnerability. The matrix approach was used to identify the conservation treatment needs for five resource concerns related to sediment, nitrogen, and phosphorus losses through surface and subsurface pathways and wind erosion. Areas requiring high, moderate, or low conservation treatment are characterized as follows:

- Acres with a high need for conservation treatment consist of the most critically undertreated acres in the river basin. These are the most vulnerable of the undertreated acres with the least conservation treatment and have the highest per-acre erosion and/or loss of nutrients.
- Acres with a moderate need for conservation treatment consist of undertreated acres that generally have lower levels of vulnerability or have more conservation practices in use than acres with a high level of need. The soil and nutrient losses are lower, and thus there is less potential on a per-acre basis for reducing agricultural pollutant loadings with additional conservation treatments.
- Acres with a low need for conservation treatment consist of acres that are adequately treated with respect to the level of inherent vulnerability. While gains can be attained by adding conservation practices to some of these acres, additional conservation treatments would reduce field losses by only a small amount.

Combinations of nutrient management practices, water erosion control practices, and irrigation management practices were used for treatment of undertreated area in the ENMA or ENMC scenarios using APEX. Flows and loads from the APEX simulations for the ENMA or ENMC scenario were used as inputs for SWAT simulations. These scenarios differ from the current conservation conditions by including additional cropland areas needing treatment with a suite of commonly prescribed treatment practices for controlling nutrient losses within acceptable levels.

Background Scenario

The background scenario was used to estimate background loads in the basin if the currently cultivated cropland was not farmed but replaced with natural vegetation. This scenario was simulated using APEX with a natural vegetation (grass-tree mix) condition on all cultivated cropland area without any tillage, nutrients, or pesticides, and flows and loads were input for SWAT simulation. Thus, the background loads included loads from non-cultivated land and point sources from SWAT combined with the natural vegetation loads from APEX. All these source loads passed through in-stream processes to include natural attenuation of sediment, nutrients, and pesticides. The goal was to determine the background load in the basin due to sources other than cultivated agriculture and with natural vegetation on cropland.

The no-practice and background scenarios were simulated to develop the upper and lower bounds of the potential benefits of conservation practices for current cultivated agriculture. The additional cropland conservation treatment scenarios (ENMC and ENMA) were developed to spatially target undertreated cropland areas where conservation practices have potential to reduce excess nutrient losses and significantly improve water quality. The background scenario provided insights on the minimal background pollutant loads that could be in the system in the absence of cultivated agriculture due to loads from sources other than cultivated agriculture, such as point sources and non-cultivated land. Conservation agencies and environmental agencies can use this information to make decisions on where to best allocate resources for future conservation planning, source load allocations in TMDL, and the hypoxia issue in the Gulf of Mexico.

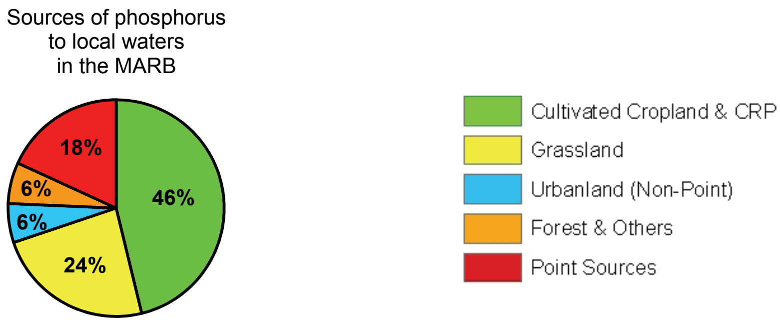
RESULTS AND DISCUSSION

MAJOR SOURCES OF TP LOADS TO LOCAL WATERS

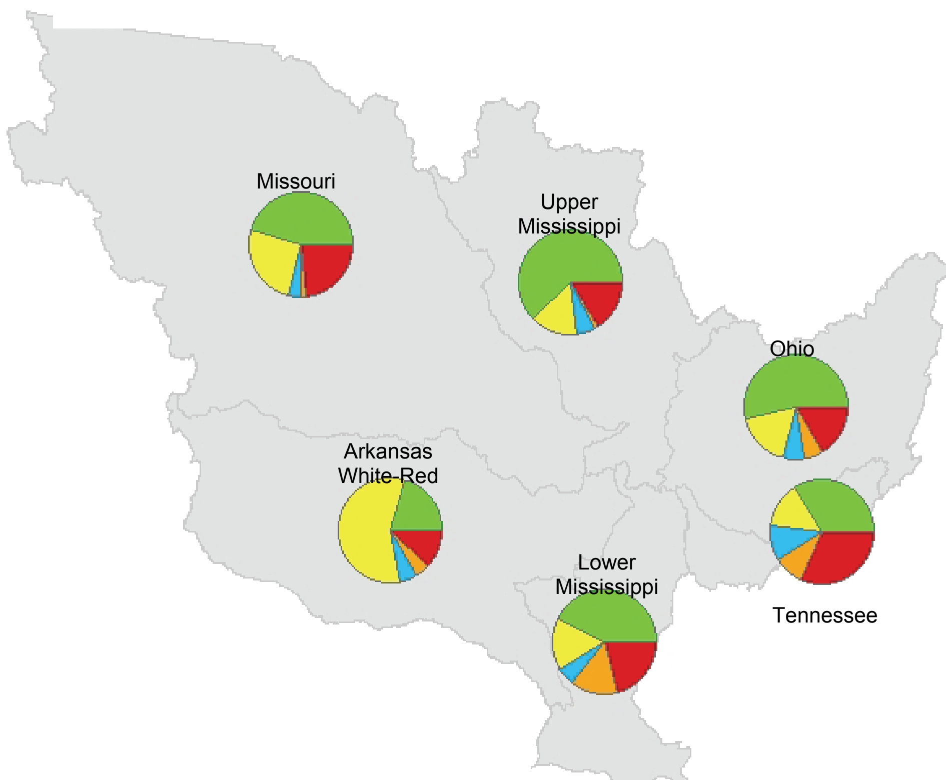
As nutrient sources are widespread in a basin with different processes, spatially locating the sources and determining their relative contributions are important for developing control measures for managing the sources and meeting the environmental goals. Source loads delivered to rivers and streams account for landscape processes, including sediment deposition, plant uptake, harvest removal, leaching, and surface and subsurface runoff transport of nutrients. Model predictions indicated that cultivated cropland was the dominant source (46%) of the P load (0.24 million tonnes) delivered to local waters from all sources. Cropland was also the dominant source of P in the Mississippi River and the Gulf of Mexico (fig. 3a), as reported in other studies (Alexander et al., 2008; USEPA, 2007). Grassland (including pasture, range, and hay lands) contributed 24% of the TP loads to local waters, mainly due to grazing animals and animal manure applications. Point-source discharges and urban nonpoint sources contributed 18% and 6%, respectively, to local waters. The source percentages of the P contribution to local waters varied among the river basins within the MARB (fig. 3b). Cultivated agriculture in the Upper Mississippi, Ohio, Lower Mississippi, and Missouri basins was the major source of P to local waters.

ANALYSIS OF EFFECTS OF CONSERVATION PRACTICE SCENARIOS ON TP LOADS

The water quality benefits due to current conservation conditions were assessed in terms of reductions in TP yields or TP loads by comparing the no-practice scenario



(a) Sources of P to local waters in the MARB



(b) Sources of P among individual river basins in the MARB.

Figure 3. Major sources of TP loads to local waters in the MARB.

with current conservation conditions. The potential additional water quality improvements that can be gained due to additional conservation treatments on undertreated cropland areas were assessed in terms of reductions in TP yields and loads by comparing the ENMC and ENMA scenarios with current conservation conditions. The effects of conservation scenarios on P were analyzed at various spatial scales in the modeling process of the MARB, as described below:

- Spatial distribution of TP yields delivered from cropland and CRP land to local waters.
- Edge-of-field TP losses from cultivated cropland and CRP land.
- TP loads delivered from cropland and CRP land to local waters.
- Instream TP loads at major river basin outlets in the MARB.
- TP loads discharged to the Gulf of Mexico.

EFFECTS OF CONSERVATION PRACTICES ON TP YIELDS TO LOCAL WATERS

Spatial Distribution and Magnitude of TP Yields

The model was used to predict the TP yields or losses (load per unit area per year) exclusively from cultivated cropland and CRP land to local waters (water bodies, rivers, and streams in the 8-digit watersheds) for the current conservation condition and additional treatment scenarios (fig. 4). Such spatial information is useful for conservation planners and water-quality managers to evaluate the relative benefits of conservation programs on cropland in different parts of a large basin, such as the MARB, and identify priority areas for additional conservation treatment. The TP yields reported here represent the aggregated edge-of-field loads from cropland for each scenario, inclusive of the delivery losses during transport from the edge of the field to the 8-digit watershed outlet. Contributions of P from cropland to local waters varied across the MARB depending on the extent and type of conservation practices implemented on the cropland, nutrient management in the fields, precipitation, surface runoff, soil type, and losses of the P through surface and subsurface waters (fig. 4 and table 1). With current conservation conditions, TP losses were high in watersheds with large cropland areas in the Upper Mississippi, Lower Mississippi, and Ohio River basins (fig. 4b). TP losses were high in these basins due to higher precipitation and runoff, as well as intensive agriculture with corn-soybean rotations. TP losses were lower (light green circles in fig. 4b) in most parts of the Missouri and Arkansas White-Red basins, primarily due to lower precipitation and runoff and less intensive agriculture. Higher rainfall, runoff, and slopes may have caused higher TP yields in the Tennessee basin, although the cropland area is less.

The conservation practices currently used on cropland were predicted to reduce average annual TP losses to local waters to 1.4 kg ha^{-1} (fig. 4b) compared to a no-practice

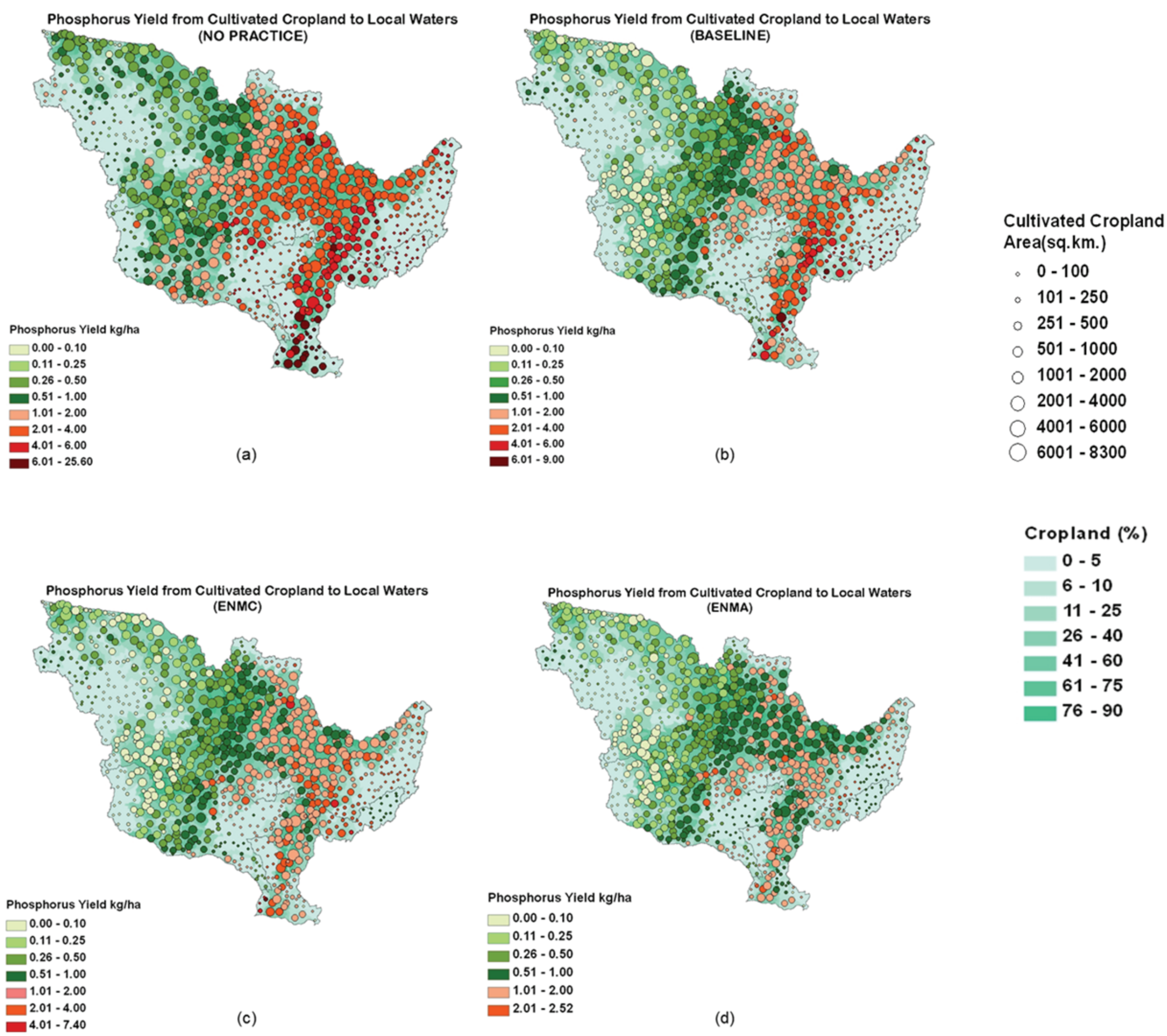


Figure 4. Spatial distribution yields from cropland to local waters for different conservation scenarios. Changes in color of the circles indicate the intensity of TP yields to local waters from cropland areas only. Variations in size of the circle indicate the variations in cropland area in 8-digit watersheds in the MARB.

condition of 2.7 kg ha^{-1} (fig. 4a). The changes in TP yields shown in figures 4a and 4b indicate that the higher TP yields in most parts of the Upper and Lower Mississippi and Ohio-Tennessee basins with no conservation practices (fig. 4a) have been reduced with current conservation (fig. 4b). Similar effects can be seen in the Missouri and Arkansas White-Red basins. Reductions in TP yields from cultivated cropland to local waters due to current conservation practices can be obtained from the difference in TP yields between figures 4a and 4b. Potential additional reductions in TP yields from cropland due to implementation of additional conservation practices can be obtained from the difference in TP yields between current practices (fig. 4b) and the additional conservation treatment scenarios, ENMC and ENMA (figs. 4c and 4d). On average, P losses of 1.0 and 0.7 kg ha^{-1} were transported to local waters from critically undertreated cropland area (fig. 4c) and all undertreated cropland area (fig. 4d), respectively. These losses were lower than the average P losses with current conservation conditions. Most of the reductions occurred in the Upper Mississippi, Lower Mississippi, and Ohio River basins because of the greater extent of critically undertreated or all undertreated cropland area in those basins (table 1) and the extent of treatment for P losses. The spatial patterns and magnitude of P yields between the scenarios (fig. 4) clearly reveal the progressive benefits of increased conservation efforts. The 8-digit watersheds with higher P yields and larger cropland areas (larger red circles in fig. 4) show priority for conservation treatment.

Frequency Classification of TP Yields

To further aid the spatial assessment, frequency analyses of TP yields from the conservation scenarios were conducted to quantify the effectiveness of USDA conservation programs in reducing TP yields (fig. 5). The effectiveness of the scenarios was shown by the shifts in the distribution of 8-digit watersheds generating higher to lower TP yields (fig. 5) through the increased conservation efforts associated with each of the conservation scenarios. For example, 67% of the 8-digit watersheds delivered TP yields ranging from 1.0 to 25.1 kg ha^{-1} with no conservation practices on the landscape, whereas only 48% and 30% of the 8-digit watersheds delivered the same range of yield with the current conservation and ENMA scenarios, respectively. The remaining 8-digit watersheds delivered less than 1.0 kg ha^{-1} with the above three scenarios. Similarly, within the 3.0 to 6.0 kg ha^{-1} category (severe losses), 33% of the 8-digit watersheds produced TP losses under no-practice conditions, whereas only 12% of the 8-digit watersheds produced the same TP losses under current conservation conditions. The percentages of 8-digit watersheds delivering 3.0 to 6.0 kg ha^{-1} TP yields were 4% and 0%, respectively, for the ENMC and ENMA scenarios. These differences in percentage distribution reflect the potential benefits that can be obtained with targeted conservation treatments on undertreated cropland areas.

Effects of Conservation Practices on Edge-of-Field TP Losses

Field-level effects of cropland conservation practices on water, sediment, and nutrients were assessed by comparing the basin-average effects for the current conservation condition (baseline) and no-practice scenarios (table 1). Edge-of-field model results showed that noticeable progress has been made in reducing TP losses from cropland (table 2) in all six basins through implementation of conservation practices (table 1). Changes in land use, conservation practices, or hydrologic conditions change the quantity of surface runoff generated, thus affecting the transport of waterborne contaminants. This effect was simulated in APEX or SWAT with changes in the curve number, as suggested in the literature for other watersheds (Arabi et al., 2008; Tuppad et al., 2010; Santhi et al., 2012). With conservation practices on the landscape, the average surface runoff from each basin was reduced due to the curve number representing the changes in land use, subsurface flow increased, and sediment and nutrient losses decreased (table 2). Runoff and erosion were the principal means of transporting P from cropland (table 2), as reported in the literature (Sharpley et al., 1994). Increased nutrient inputs applied through fertilizer and manure on cropland caused higher TP losses compared to CRP land, where no fertilizer was applied. TP losses from farm fields (load per unit area) were lowest in the Missouri basin and highest in the Ohio-

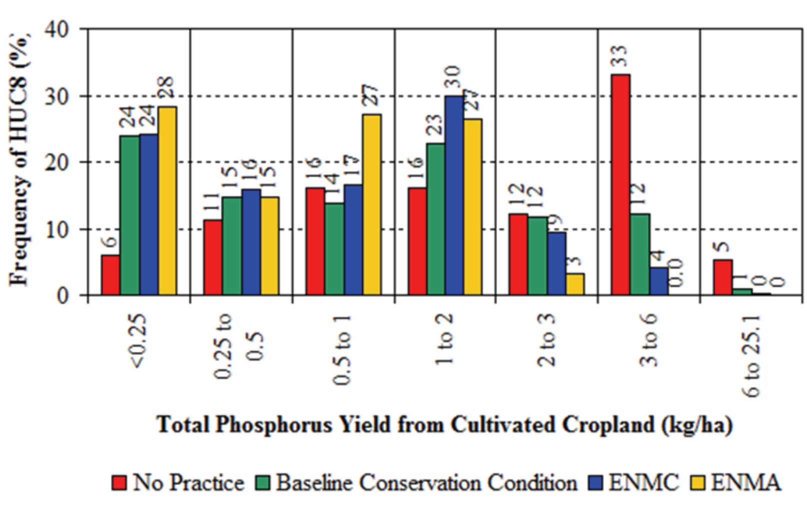


Figure 5. Frequency classifications of TP yields from cultivated cropland for different conservation scenarios.

Table 2. Field-level effects of conservation practices on average annual water, sediment, and TP losses from cultivated cropland and land in long-term conserving cover in the Mississippi-Atchafalaya River basin (source: USDA-NRCS, 2011 2012a, 2013).[a]

	Upper Mississippi			Ohio-Tennessee			Missouri			Arkansas White-Red			Lower Mississippi		
Constituent and Unit	BL	NP	%R	BL	NP	%R	BL	NP	%R	BL	NP	%R	BL	NP	%R
Cultivated cropland															
Surface runoff (mm)	112	124	10	193	211	8	33	46	28	61	81	25	340	384	11
Subsurface flow[b] (mm)	152	137	-11	236	213	-11	79	69	-15	66	66	0	269	239	-13
Edge-of-field sediment loss with erosion (t ha^{-1})	2.0	5.1	61	3.6	7.4	52	0.6	2.2	73	0.8	1.9	61	6.8	9.3	27
TP losses (kg ha^{-1})	3.6	6.4	44	5.1	7.7	33	1.9	4.6	58	2.6	5.0	48	6.0	10.0	39
P loss with surface runoff including waterborne sediment (kg ha^{-1})	3.0	5.3	43	5.1	7.6	33	0.8	1.8	59	1.0	2.2	57	5.8	9.6	40
Long-term cover conservation (CRP land)															
Surface runoff (mm)	76	127	40	183	257	29	13	38	67	10	46	78	206	361	43
Subsurface flow[b] (mm)	226	140	-62	310	218	-42	41	53	24	28	48	42	5	3	-100
Edge-of-field sediment loss with erosion (t ha^{-1})	0.47	12.3	96	0.4	18.5	98	0.04	2.8	98	0.02	1.3	98	0.18	25.7	99
Total P losses (kg ha^{-1})	0.6	8.5	93	0.8	11.4	93	0.1	5.6	99	0.03	1.7	98	0.4	15.2	98
P loss with surface runoff including waterborne sediment (kg ha^{-1})	0.5	8.3	94	0.7	11.4	94	0.1	2.1	97	0.02	1.2	98	0.3	15.1	98

[a] BL = baseline or current conservation condition, NP = no-practice scenario, and %R = percent reduction.
[b] Negative %R values indicate an average gain in subsurface flow for land in long-term conserving cover.

Tennessee basin. Relatively lower annual precipitation, less intensive agriculture (table 2), and widespread use of soil erosion control and nutrient management practices (table 2) caused lower field losses of TP in the Arkansas White-Red and Missouri River basins compared to the Upper and Lower Mississippi and Ohio-Tennessee basins (table 2). Field losses of TP (table 2) with baseline conservation conditions were within the reported ranges (0.26 to 18.6 kg ha^{-1} $year^{-1}$) for row crops (Reckhow et al., 1980). The TP losses reported for the Arkansas White-Red basin (table 2) are similar to the range reported by Tuppad et al. (2010) for Mill Creek watershed in Texas using APEX (TP losses of 2.8 kg ha^{-1} for suites of contour farming, conservation cropping, and nutrient management practices). Since the hydrological setting and basin characteristics of other basins in the MARB are different from those of Tuppad et al. (2010), the effects of conservation practices on water quality varied differently. Field TP losses for the additional treatment scenarios (ENMC and ENMA) were lower than the current conservation condition (not shown here). Flow and field losses of sediment, nutrients, and pesticides simulated from cultivated cropland and CRP land using APEX for each scenario (table 2) were input to SWAT to estimate the extent to which conservation practices have reduced the loads from cropland or instream loads in the rivers.

Effects of Conservation Practices on Local Watershed TP Loads

The CEAP model predicted that 0.111 million metric tonnes of TP per year were delivered to local waters from cultivated cropland and CRP land in the MARB under current conservation conditions, with varied amounts of TP contributed by each basin (fig. 6). Figure 6 summarizes the extent to which current and additional conservation practices on cultivated cropland and CRP land have reduced the TP loads in each basin by aggregating the loads from all 8-digit watersheds due to cropland and CRP land only. In terms of percent reductions, current conservation practices were more effective (by more than 50%) in reducing TP loads delivered from cropland and CRP land to local waters in the Missouri, Arkansas White-Red, and Lower Mississippi River basins when compared to 13% to 41% reductions in the Upper Mississippi and Ohio-Tennessee basins (fig. 6). Current practices were more effective in the Missouri and Arkansas White-Red basins due to less precipitation and runoff, less intensive agriculture (table 1), lower field nutrient losses (table 2), and widespread use of conservation practices (table 1) when compared to the other basins. As a result of higher precipitation and runoff, intensive agriculture, and higher field losses (tables 1 and 2), additional conservation treatments are required in the Ohio-Tennessee and Upper and Lower Mississippi basins (table 1). Hence, further potential reductions of 41% to 71% in TP loads delivered from cropland to local waters can be obtained from the baseline conditions in the Upper Mississippi, Ohio, Tennessee, and Lower Mississippi basins with additional treatment on all undertreated area (ENMA) (fig. 6). Thus, future conservation efforts can be targeted in these basins to obtain greater benefits.

Effects of Conservation Practices on Instream and Riverine TP Loads

As the Mississippi River flows downstream, flows and loads accumulate and increase due to the contributions from each tributary basin. Figure 7 summarizes the extent to which current and additional conservation practices on cultivated cropland and CRP land have reduced the instream TP. Of the 0.24 million metric tonnes of TP per year delivered to local waters from all sources (cropland, noncropland, and point sources) under current conservation conditions, SWAT predicted that 0.15 million metric tonnes per year was delivered to the Gulf of Mexico, with the remaining TP load being sequestered or lost in lakes, reservoirs, rivers, and streams. Model simulations indicated that an average of 0.15 million metric tonnes of TP per year is delivered to the Gulf of Mexico with current conserva-

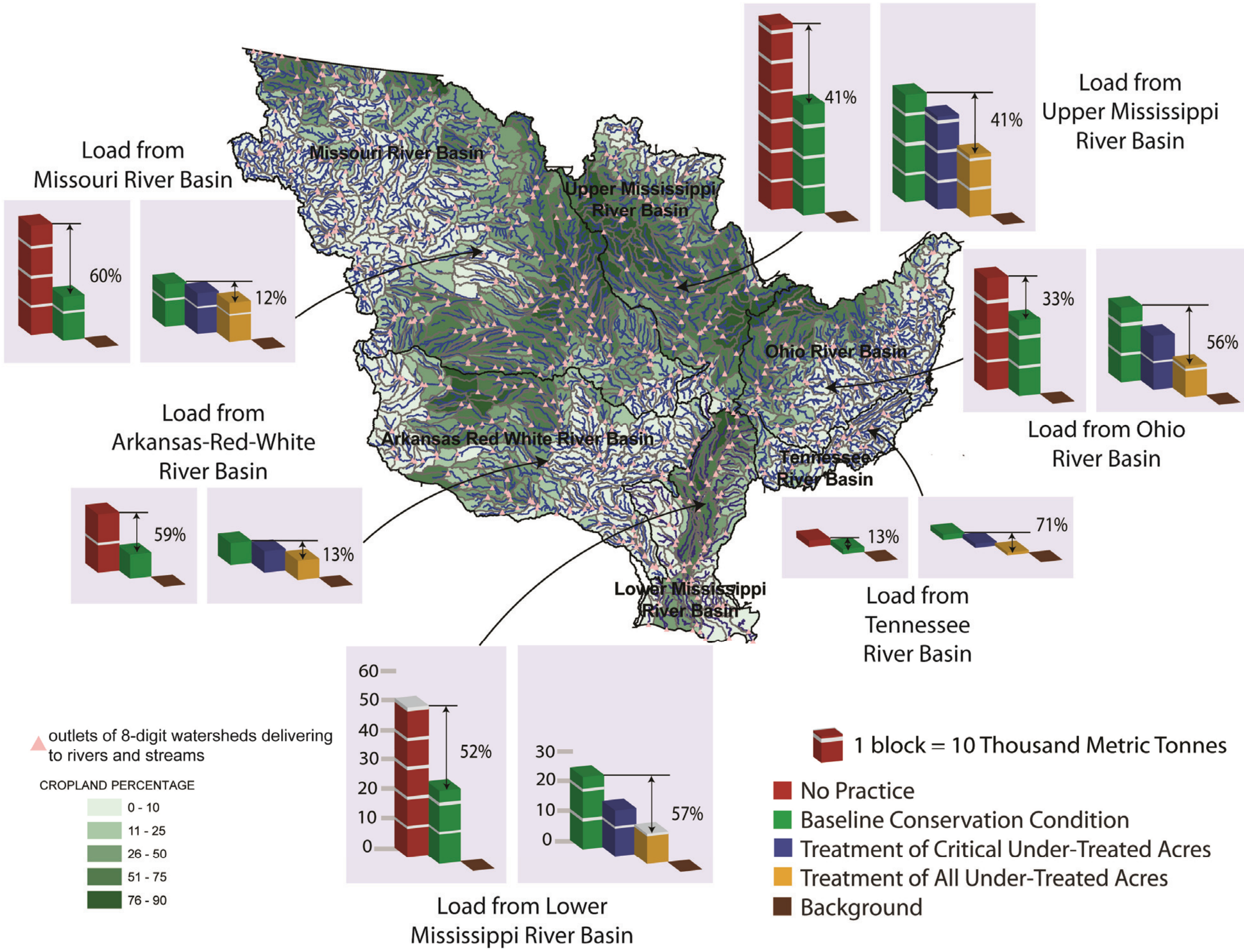


Figure 6. Effects of cropland conservation practice scenarios on P loads delivered from cropland to local waters in the MARB.

tion conditions (fig. 7). Major reservoirs in Missouri (Brown et al., 2011) and the Tennessee, Arkansas, and Red River basins trap sediment and TP loads. With the implementation of additional conservation treatment practices on all undertreated cropland areas (ENMA), an average of 0.13 million metric tonnes of TP per year is expected to be discharged to the Gulf of Mexico from the MARB (fig. 7). Model results indicated that current conservation practices on cropland have led to a reduction of 20% to 28% in the instream TP loads delivered from the Upper Mississippi, Missouri, Ohio-Tennessee, and Lower Mississippi-Atchafalaya basins to the Mississippi River, as compared to the no-practice scenario. Current practices have reduced the loads from the Arkansas White-Red basin to the Mississippi River by 17% (fig. 7) compared to the no-practice scenario. With implementation of additional conservation treatment practices on all undertreated cropland area (fig. 7), delivery of TP from the Upper Mississippi, Lower Mississippi, and Ohio-Tennessee basins to the Mississippi River can be further reduced by 12% to 31% from current conservation conditions.

Model results indicated that current conservation practices have reduced TP loads delivered to local waters in all river basins in the MARB (fig. 7) and to instream waters in the Missouri, Arkansas White-Red, and Lower Mississippi basins (fig. 7). Since the extent of the additional conservation treatment required in the Upper and Lower Mississippi and Ohio-Tennessee basins is higher (table 1), opportunities exist for obtaining major reductions in TP loads delivered to local and instream waters by focusing future conservation treatment efforts on these basins.

The maximum potential benefit of future conservation could be reasonably determined by comparing current conservation conditions with background conditions. White et al. (2014) discussed the effects of current conservation practices in the context of nutrient delivery to the Gulf of Mexico. That approach is different from this study, which focused on the effects of different conservation conditions on P loads discharged to local and instream waters.

CEAP Conservation Scenarios and Hypoxia Target Load Reduction

The Mississippi River Watershed and Gulf of Mexico Hypoxia Task Force recommended target load reductions of 45% in annual TP loads delivered to the Gulf of Mexico from the Mississippi River (shown by purple bars in fig. 7) to reach the goal of reducing the hypoxic zone to less than 5,000 km^2 by 2015. Other studies have emphasized including both N and P in hypoxia load reduction strategies (Rabalais et al., 2002; Sylvan et al., 2006; Jacobson et al.,

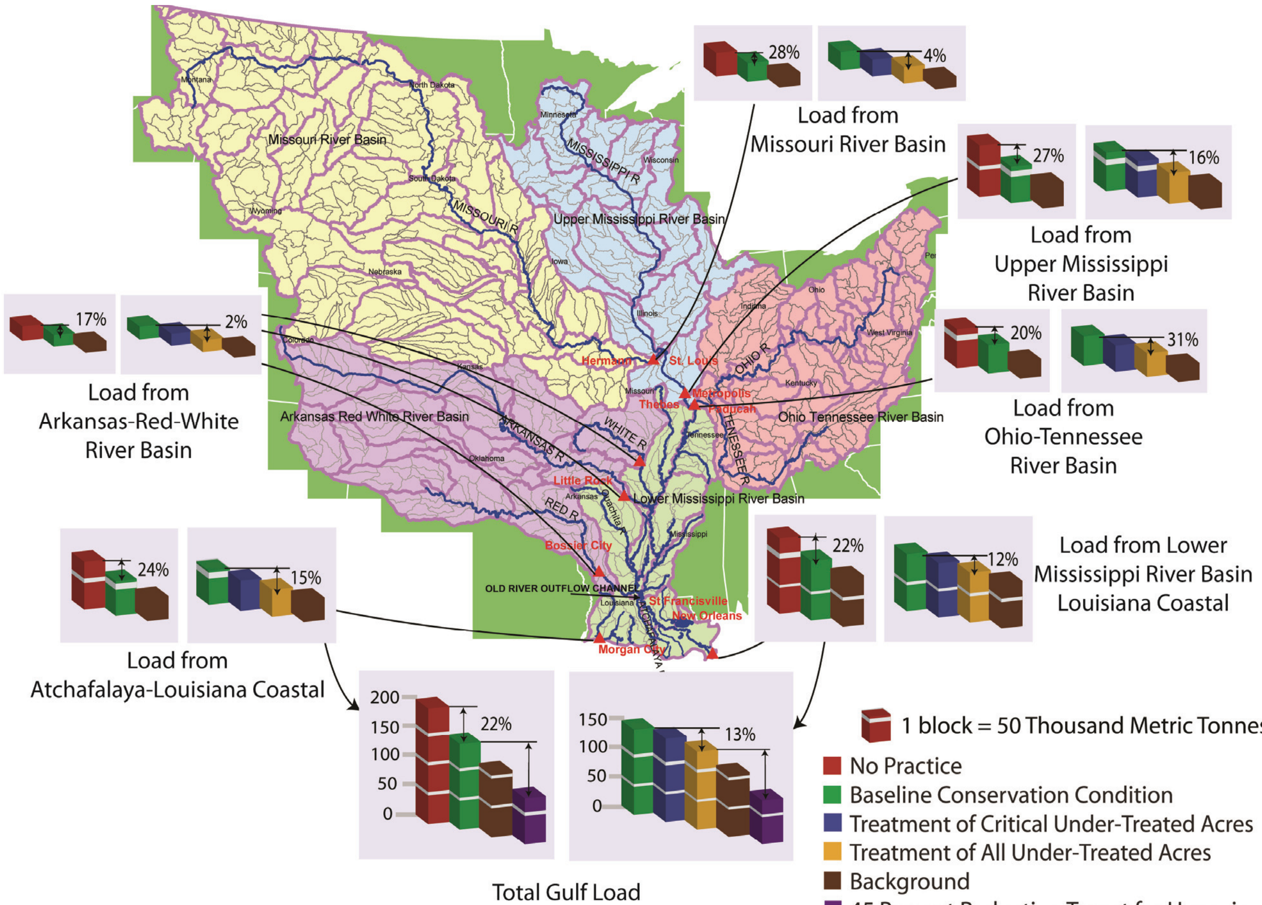


Figure 7. Effects of cropland conservation practice scenarios on instream TP loads in the MARB and total load exported to the Gulf of Mexico.

2011; Scavia and Donnelly, 2007). TP loads discharged to the Gulf of Mexico with the current conservation condition remain above the hypoxia target load. A further TP load reduction of 43% from the baseline conservation condition is likely required to reach the hypoxia target load. Scavia and Donnelly (2007) suggested a similar reduction range (40% to 50%) based on their study. The ENMA scenario provided an estimate of the loads with maximum agricultural conservation efforts using commonly prescribed conservation practices. TP discharged to the Gulf of Mexico with additional conservation treatment on all undertreated cropland (ENMA) is not adequate to reach the target load. A further load reduction of 35% from ENMA is likely required (fig. 7). This implies that a focus on other sources of TP loads, such as point-source discharges from major cities, grassland, and urbanized areas, and TP control strategies are required in addition to cultivated agriculture. Jacobson et al. (2011) emphasized the need for focusing on TP sources and control strategies beyond fertilizers and manures. Point sources contribute significant TP loads to local water bodies (fig. 7). The EPA's Science Advisory Board on hypoxia (USEPA, 2007) and Jacobson et al. (2011) have urged that focus be placed on TP from point-source discharges from municipalities, major cities, and intensive agriculture. The background scenario provides insight on the estimates of expected loads from other sources, such as point sources and non-cultivated land. The background scenario TP load also remains above the hypoxia target load (fig. 7). This also signals the need for more control strategies.

Diversified management efforts for agricultural land, grassland, and point-source discharges from cities and municipalities, as well as for riparian zones, P from streambank erosion, and deposits of P in bed sediments might be required to reduce the TP loads discharged to local rivers, the Mississippi River, and the Gulf of Mexico (USEPA, 2007; Alexander et al., 2008; Keeney, 2006; David et al., 2010). Potential agricultural management options suggested in the literature to reduce P in the MARB include incorporation of fertilizers and manure (Jacobson et al., 2011), introduction of perennial crops for energy and fuel production, continuous cover crops, and including buffer strips in Midwest agriculture (Keeney, 2006).

Quantitative assessment of the existing conservation programs provides an evaluation of the benefits achieved in each river basin. Prediction of the potential benefits of additional conservation practices provides information on where to target future programs. The information from this study can be used to guide decisions about where to focus management efforts to improve local water quality in the MARB and reduce P losses to the Gulf of Mexico.

SUMMARY AND CONCLUSIONS

Modeling is a feasible option for evaluating the effects of conservation programs and dollars spent. The CEAP modeling framework was applied to assess how P loads delivered to local waters and the Mississippi River network could be reduced due to (1) currently established conservation practices on cropland, and (2) additional conservation treatment on all undertreated cropland area. This study showed where P loads can be reduced in the MARB. This study also determined how agricultural conservation practices for P loads discharged from the MARB to the Gulf of Mexico can help achieve the recommended annual P target load for hypoxia reduction. Major conclusions of the study are:

- Cultivated agriculture in the Upper Mississippi (33%), Ohio (22%), Lower Mississippi (22%), and Missouri (13%) basins is the major source of P to rivers and streams in the MARB and to the Mississippi River. Point-source discharges and grassland are next major sources of phosphorus in the MARB.
- Spatial distribution and frequency analyses of TP losses for different conservation scenarios indicate how conservation programs reduce TP losses from cropland to achieve lower losses in different parts of the MARB with increased conservation efforts. These analyses also allow conservation groups and water quality managers in the MARB to focus on where to invest in conservation practices to get the most benefit in the MARB.
- Currently established conservation practices were effective in reducing TP losses from cropland to local waters by more than 50% in the Missouri, Arkansas White-Red, and Lower Mississippi basins compared to the Upper Mississippi and Ohio-Tennessee basins, where the reductions varied from 13% to 41%. With additional conservation treatment on all undertreated cropland area (ENMA), opportunities exist to obtain additional benefits of 41% to 71% by reducing the TP loads delivered from cropland to local waters in the Upper Mississippi, Ohio, Tennessee, and Lower Mississippi basins.
- Current conservation practices have reduced the TP loads discharged to the Gulf of Mexico by 22%. An additional reduction of 13% in TP loads can be potentially obtained with additional conservation treatments on undertreated cropland areas.
- The conservation scenarios provide estimates of the potential bounds of water quality benefits that could be obtained due to agricultural conservation, background loads in the system in the absence of cultivated agriculture, and targeting undertreated areas to get major benefits. Conservation agencies and environmental agencies can use this information to make decisions to allocate resources for future conservation planning and source load allocations for TMDL and hypoxia reduction.
- A further TP load reduction of 43% from the baseline conservation condition is likely required to reach the 45% reduction target in annual TP load for hypoxia. A 35% reduction in TP discharged from additional conservation treatment conditions is required to reach this target. This analysis has provided insights on how prescribed agricultural conservation treatments can help achieve the hypoxia target. The gaps that exist in meeting the hypoxia target should be bridged with diversified management efforts focusing on all sources of P in the MARB, including conservation practices in cultivated agriculture.

The integrated modeling approach developed for assessment of conservation practices as part of the CEAP cropland national assessment, including databases, processes, and findings complied from CEAP watershed studies, can be applied to other watersheds with some modifications. The minimum modeling and data requirements for such applications are as follows:

- Details on the conservation practices (types and acres) implemented in the watershed.
- Processes and conservation practice algorithms specific to the watershed, such as tile drains, cover crops, channel erosion, animal waste management, fertilizer rate and timing, riparian processes, and others as needed.
- Procedures for integrating APEX and SWAT for the given watershed, including the delivery ratio.

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APPENDIX

APEX AND SWAT MODEL DESCRIPTIONS

APEX is a field-scale physical process model developed to simulate complex land management and conservation practices and evaluate the impacts on soil, water quality, and agricultural production (Williams and Izaurralde, 2006). Gassman et al. (2010) provided a detailed review of APEX applications. The model simulates upland hydrology, farming operations, crop growth, and fate and transport of water, soil, sediment, nutrients, carbon, and pesticides from multiple fields or farms.

SWAT is a comprehensive process-based model used to evaluate the impacts of different land management conditions on water quality in large watersheds (Arnold et al., 1998; Neitsch et al., 2002). Gassman et al. (2007) and Douglas-Mankin et al. (2010) provided comprehensive reviews of SWAT developments and applications. In SWAT, a river basin or watershed is divided into subbasins. Each subbasin is divided into several land use and soil combinations called hydrologic response units (HRUs), and a set of land management practices is assigned to each HRU. SWAT simulates upland processes, such as weather, hydrology, farming operations, crop growth, depositions of atmospheric N, and fate and transport of water, sediment, nutrients, and pesticides, from HRUs to each subbasin or 8-digit watershed outlet. In CEAP, while APEX is used to simulate the cultivated cropland and conservation practices in a river basin, SWAT is used to (1) simulate the remaining non-cultivated land and point-source discharges, and (2) simulate the movement, transformations, and/or losses of water, sediment, nutrients, and pesticides through channels, reservoirs, and lakes to the basin outlet.

Simulation of Cultivated Cropland, CRP Land, and Non-Cultivated Land

In this study, APEX was used to simulate upland processes, as indicated above, from cultivated cropland and CRP land consisting of multiple fields or farms. For each river basin, the cropping systems (single crop, two crops, and rotational crops) and land management information were obtained from the CEAP farmer survey and used in cropland simulation. A statistically designed sampling approach was used in the CEAP survey by selecting a subset of the National Resources Inventory (NRI) sampling units (Goebel, 2009). Sampling was conducted for cropland fields in order to obtain a full representation of the diversity of cropping systems, resource concerns, farming activities, conservation practices, soils, climate, and other natural resource conditions on cultivated cropland. Survey data for 12,758 cropland sample points and 9,103 CRP points over a four-year period (2003-2006) were collected in the MARB (Jay Atwood, USDA-NRCS, personal communication, March 2014). Typically, 1 to 20 cropland points are simulated in each 8-digit watershed using APEX. The farmer survey points chosen were greater if the cropland in each 8-digit watershed was greater, and vice-versa. All sample points within each 8-digit watershed were chosen for the CEAP farmer survey. These were referred as representative CRP land. Six vegetative cover types, (introduced grass, native grass, trees, softwood, hardwood, and wetland) were identified for planting on CRP land simulation. Each sample point was assigned one of the six vegetative cover types. Farm Survey Agency (FSA) CRP sign-up contract data (USDA-FSA, 2004) and/or NRI database were used for determining the vegetative cover and practices used on CRP land. The species mix specific to a region for each of the six cover types was identified for each NRCS-defined Land Resource Region by an expert panel of CEAP modelers. Using the database developed from the above procedure, the cover establishment on each CRP point in an 8-digit watershed was simulated. It always included at least one grass type and a legume planted at 1/4 of the density to supply nitrogen, in addition to the identified vegetative cover. CRP land is usually established on highly erodible or leaching cultivated cropland. The field operation schedules consisted of planting operations for vegetative species, a harvest operation for tree species, and annual weed control (mowing or clipping) for non-tree species. The CRP simulations have no fertilizer, manure, or pesticide inputs. If there were practices on cultivated land, they were assumed to continue during the CRP enrollment in the baseline. The field losses simulated from the sampled CRP land per unit area were area weighted for CRP land in each 8-digit watershed to estimate the losses for the entire CRP area in that 8-digit watershed.

SWAT was used to simulate the upland processes from non-cultivated land use HRUs. Manure information were derived from livestock population data available in the 2002 Census of Agriculture (Kellogg and Moffitt, 2011) and used in pasture, range, and hay land simulations. Continuous grazing operations were also included on pasture and range land simulations. N fertilizer and irrigation applications were included in simulating the grassed urban areas and lawns. Sediment and nutrients carried with stormwater runoff from impervious urban areas were estimated using the buildup/washoff algorithm in SWAT (Nietsch et al., 2002). Horticultural lands were simulated to represent orchards and vegetables with applications of N and P fertilizers.

Model Calibration and Validation

River basin models within the MARB were calibrated and validated before applying them for scenario assessment. In this study, calibration was performed on a process basis by focusing on different model components such as water yield, streamflow, upland erosion, channel erosion, and nutrients transported in different flow pathways in the basin. Spatially distributed calibration was adopted for calibrating the water yield, surface runoff, and base flow at the subwatershed level. Long-term multi-site and multi-parameter calibration was adopted for calibrating streamflow, sediment, and nutrients, as suggested in the literature (White and Chaubey, 2005).

Spatial Calibration of Water Yield

The SWAT and APEX models set up for the MARB with current conservation condition were both calibrated to capture the spatial variation in long-term average annual water yield, base flow, and surface runoff for each 8-digit watershed using a spatial flow calibration procedure (Kannan et al., 2008; Santhi et al., 2008a), USGS average annual runoff estimates (Gebert et al., 1987), and base flow estimates (Santhi et al., 2008b). Average annual water yield, base flow, and runoff from the model were calibrated until they were within 20% to 25% of the estimated values. This is important for calibration of nutrients during low-flow conditions and simulation of nutrient reduction scenarios. Spatial water yield calibration for each 8-digit watershed helps to (1) capture the spatial variation in hydrology and local water balance, and (2) obtain predicted streamflows that are closer to the observed values.

Calibration Procedure for Streamflow, Sediment, and Nutrients

The APEX portion of the MARB model was calibrated for upland erosion, N, P, and pesticide loads from farm fields (Williams et al., 2010; Wang et al., 2012; Santhi et al., 2014). As described by Santhi et al. (2014) and White et al. (2014), semi-automated calibration programs were used for streamflow, sediment, and nutrient calibrations at multiple gauges that involved numerous iterations of SWAT model runs to minimize the percent bias (PBIAS) or prediction difference (objective function) between observed and simulated constituents. The number of model parameters used in the calibration program was kept to a minimum (approx. 10 to 20 parameters per constituent). Parameters were adjusted within reported ranges (Santhi et al., 2014). A semi-automated calibration approach was preferred for CEAP as it provided opportunity for intermediate verification of model performance and application of corrections, if needed. Sediment and nutrient loads required for calibration were estimated using the USGS LOADEST program (Runkel et al., 2004), measured streamflow, and grab sample concentrations of sediment and nutrients. Calibration statistics, including percent bias (PBIAS), ratio of the root mean square error to the standard deviation of measured data (RSR), Nash-Sutcliffe efficiency (NSE; Nash and Sutcliffe, 1970), and coefficient of determination (R^2), were chosen for judging the model calibration performance. The calibration evaluation guidelines provided by Moriasi et al. (2007) and the upper and lower confidence intervals (95%) of observed loads at the CEAP gauging stations were used for judging model performance. Streamflow calibration was conducted until the observed and simulated flows were within 15% to 20% of observations. Nutrient calibrations were conducted until the predicted nutrient loads were within the confidence interval limits of observed loads and with lower PBIAS. Further details on the calibration procedure used in CEAP and on APEX and SWAT parameterization can be found in Santhi et al. (2014) for the Ohio basin, and calibration and validation for stations in the MARB are briefly described by White et al. (2014).

Calibration Results for Annual Streamflow and Total Phosphorus

The 38 USGS stream gauges were selected for calibration based on location, drainage area, and the availability of flow, sediment, and nutrient data. The MARB model with current conservation conditions was calibrated for annual streamflow, sediment, nitrogen, and phosphorus at these gauges, which are located at major rivers and their tributaries, between 1961 and 2006, depending on data availability. The R^2 and NSE values estimated between average annual observed and predicted TP loads across the 38 gauges were 0.98 and 0.98, respectively. The R^2 and NSE were respectively 0.98 and 0.99 for streamflow at these gauges (White et al., 2014). The calibrated average annual TP loads at a few important gauges located at the outlets of the Mississippi River and for major rivers in each basin that have confluence with the Mississippi River (table A-2) were included to show the model performance and compare the observed loads with predicted loads of the conservation scenarios (fig. 7). Time series results of calibrated annual P loads at St. Francisville, Louisiana (fig. A-1) are shown for the same reasons. The calibrated average annual TP loads at the gauges had low PBIAS (≤25% for most of the gauges). The predicted average annual TP loads were also within confidence interval limits of the observed loads (table A-1). The RSR values were lesser than 0.70 at most of the gauges (table A-1). The NSE values between the annual predicted and observed TP loads were greater than 0.25 at most of the gauges (table A-1). These statistics indi-

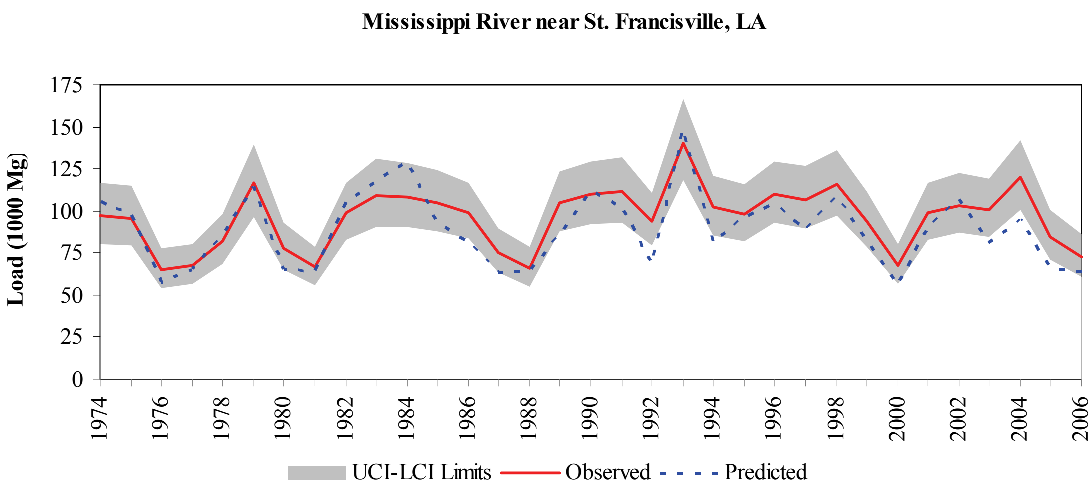

Figure A-1. Comparison of time series observed and simulated annual TP loads at St. Francisville, Louisiana, on the Mississippi River after calibration.

Table A-1. Observed and simulated annual TP loads at selected calibration gauging stations in the Mississippi-Atchafalaya River basin (TP loads are in metric tonnes).

Gauging Station	HUC[a]	Predicted	Lower End of Confidence Interval	Observed	Upper End of Confidence Interval	PBIAS[b]	RSR[c]	NSE[d]
Ohio River at Metropolis, Ill. (G8)	5140206	42,183	35,807	48,000	63,378	-12	0.73	0.47
Missouri River at Hermann, Mo. (G4)	10300200	25,925	19,720	30,247	44,820	14	0.77	0.41
Mississippi River at Grafton, Ill. (G2)	7110009	28,154	21,854	28,604	36,925	2	0.26	0.41
Mississippi River at Thebes, Ill. (G5)	7140105	59,544	52,483	68,279	87,657	13	0.23	0.95
White River near Calico Rock, Ark.(G18)	11010003	205	134	212	319	3	0.59	0.66
Red River at Alexandria, La. (G11)	11140207	7,011	5,560	7,075	8,877	1	0.41	0.83
Arkansas River at Murray Dam, Ark. (G10)	11110203	4,804	4,343	5,177	6,125	4	0.25	0.94
Mississippi River at Vicksburg, Miss. (G17)	08030100	128,747	96,729	118,768	144,411	-8	0.86	0.25
Mississippi River near St. Francisville, La. (G12)	08070100	89,307	80,273	95,941	113,770	7	0.70	0.50
Atchafalaya River at Melville, La. (G13)	08080101	45,282	31,414	40,615	51,920	-18	1.1	-0.3

[a] HUC = Hydrologic Unit Code.
[b] Negative values indicate model overprediction bias, positive values indicate model underprediction bias, and 0 indicates optimal prediction.
[c] RSR values closer to 0.0 indicate optimal model predictions, and values between 0.0 and 0.70 are acceptable
[d] NSE values closer 1 indicate better model predictions, and values between 0.0 and 1.00 are acceptable (Moriasi et al., 2007).

cate satisfactory model calibration performance. Diversion of streamflow and associated nutrients from the Mississippi River to the Atchafalaya River through Old River Outflow Channel resulted in overprediction of TP loads in the Atchafalaya River at Melville, Louisiana (G13) and underprediction at St. Francisville, Louisiana (G12) on the Mississippi River (fig. 2). Hence, the RSR and NSE values at Melville Station were lower than the acceptable level (table A-1).

VALIDATION RESULTS FOR ANNUAL STREAMFLOW AND TOTAL PHOSPHORUS

The MARB model was validated for average annual streamflow and TP at 17 additional uncalibrated gauging stations using the average annual observations from the USGS (Saad et al., 2011). The R^2 and NSE values between observed and predicted average annual streamflow for the 17 validation gauges were 0.98 and 0.95, respectively. The R^2 and NSE values between observed and predicted average annual TP loads for the 17 validation gauges were 0.82 and 0.78, respectively (White et al., 2014). These results indicate good correlations in model predictions.

VALIDATION RESULTS FOR SPRING STREAMFLOW AND TOTAL PHOSPHORUS

Sylvan et al. (2006), Scavia and Donnelly (2007), and USEPA (2011b) indicated that P limits phytoplankton growth in the Gulf of Mexico during spring and summer and that P plays an important role in the development of the hypoxic zone. Hence, in this study, spring (averages for April, May, and June) streamflows and nutrient loads were compared at 15 USGS gauges in the MARB (Battaglin et al., 2010) for the period from 1980 to 2006 to evaluate model performance for the spring months. The model was not calibrated for spring.

Averages of observed and predicted spring streamflow matched well (fig. A-2), i.e., within 25%, for more than half of the gauges studied (table A-2). Similarly, averages of observed and simulated spring TP loads were within the PBIAS reported for monthly loads (Moriasi et al., 2007) (fig. A-2 and table A-2). The R^2 values of 0.95 for streamflow and 0.97 for P indicate further agreement between spring observations and predictions at the gauges (fig. A-2). Overall, the calibration and validation results provide confidence in the performance of both models, so that the combined model can be used for simulating the various conservation scenarios.

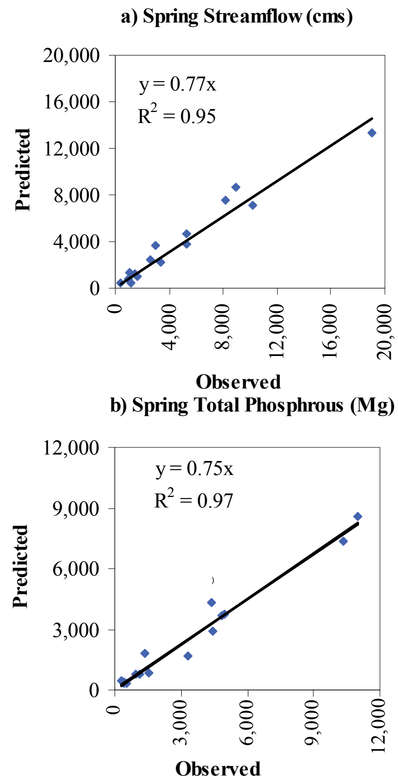

Figure A-2. Comparison of spring average observed and predicted (a) streamflow and (b) TP at selected gauging stations in the MARB.

Table A-2. Percent bias (prediction difference) between observed and predicted spring streamflow and P at selected calibration gauges in the Mississippi-Atchafalaya River basin.

Gauging Station	Gauge ID	Drainage Area (km^2)	PBIAS[a] Spring Flow	PBIAS[a] Spring TP
Mississippi River, Clinton, Iowa	G1	2.22 E+05	7	-35
Mississippi River, Grafton, Ill.	G2	4.44 E+05	13	1
Missouri River, Omaha, Neb.	G3	8.36 E+05	-36	45
Missouri River, Hermann, Mo.	G4	1.35 E+06	-23	34
Mississippi River, Thebes, Ill.	G5	1.84 E+06	3	29
Ohio River, Greenup, Ky.	G6	1.61 E+05	33	32
Ohio River, Cannelton, Ind.	G7	2.51 E+05	29	49
Ohio River, Grand Chain, Ill.	G8	5.26 E+05	31	24
Tennessee River, Paducah, Ky.	G9	1.04 E+05	20	-46
Arkansas River, Little Rock, Ark.	G10	4.09 E+05	40	38
Red River, Alexandria, La.	G11	1.74 E+05	62	28
Mississippi River, St. Francisville, La.	G12	2.91 E+06	30	22
Atchafalaya River, Melville, La.	G13	2.41 E+05	7	24
Iowa River, Wapello, Iowa	G14	3.24 E+04	0	12
Illinois River, Valley City, Ill.	G15	6.93 E+04	13	17

[a] Negative values indicate model overprediction bias, positive values indicate underprediction bias, and 0 indicates optimal prediction.